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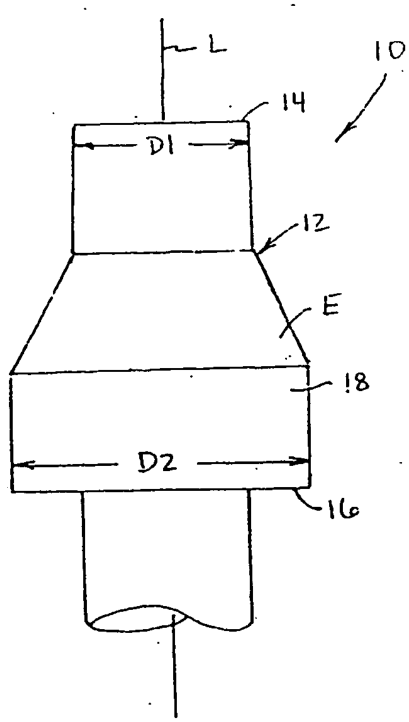
(54) Title: RESIDUAL STRESSES IN EXPANDABLE TUBULAR CASING



(57) Abstract: An elongated section of steel tubing has an outer circumferential surface and an inner circumferential surface defining an elongated axial passage through the tubing. An expansion mandrel is moved through the tubing for radially expanding the tubing. An impact member is provided for travel through the length of the axial passage. A plurality of movable impactors are mounted to extend from the impact member. The impactors are driven for repeated contact with the inner circumferential surface as the impact member is moved through the tubing subsequent to the expansion mandrel for contacting the expanded inner circumferential surface along the entire length of the axial passage. Movement of the impactors is ultrasonic.

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RESIDUAL STRESSES IN EXPANDABLE TUBULAR CASING

Cross Reference To Related Applications

[001] The present application claims the benefit of the filing dates of (1) U.S. provisional patent application serial no. 60/412,177, attorney docket no 25791.117, filed on 9/20/2002, the disclosure of which is incorporated herein by reference.

[002] The present application is related to the following: (1) U.S. patent application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, (3) U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, (4) U.S. patent no. 6,328,113, (5) U.S. patent application serial no. 09/523,460, attorney docket no. 25791.11.02, filed on 3/10/2000, (6) U.S. patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, (7) U.S. patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, (8) U.S. patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, (9) U.S. patent application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, (10) PCT patent application serial no. PCT/US00/18635, attorney docket no. 25791.25.02, filed on 7/9/2000, (11) U.S. provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (12) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (13) U.S. provisional patent application serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (14) U.S. provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed on 10/12/1999, (15) U.S. provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (16) U.S. provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (17) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (18) U.S. provisional patent application serial no. 60/221,443, attorney docket no. 25791.45, filed on 7/28/2000, (19) U.S. provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (20) U.S. provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (21) U.S. provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (22) U.S. provisional patent application serial no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001, (23) U.S. provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001, (24) U.S, provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001, (25) U.S. provisional patent application serial no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001, (26) U.S. provisional patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on 8/20/2001, (27) U.S. provisional patent application serial no. 60/317,985, attorney docket no. 25791.67, filed on 9/6/2001, (28) U.S. provisional patent application serial no. 60/3318,386, attorney docket no. 25791.67.02, filed on 9/10/2001, (29) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (30) U.S. utility patent

application serial no. 10/016,467, attorney docket no. 25791.70, filed on 12/10/01, (31) U.S. provisional patent application serial no. 60/343,674, attorney docket no. 25791.68, filed on 12/27/2001, (32) U.S. provisional patent application serial no. 60/346,309, attorney docket no 25791.92, filed on 1/7/2002, (33) U.S. provisional patent application serial no. 60/372,048, attorney docket no. 25791.93, filed on 4/12/02 (34) U.S. provisional patent application serial no. 60/380,147, attorney docket no. 25791.104, filed on 5/6/2002, (35) U.S. provisional patent application serial no. 60/387,486, attorney docket no. 25791.107, filed on 6/10/2002, (36) U.S. provisional patent application serial no. 60/387,961, attorney docket no. 25791.108, filed on 6/12/2002, (37) U.S. provisional patent application serial no. 60/391,703, attorney docket no. 25791.90, filed on 6/26/2002, (38) U.S. provisional patent application serial no. 60/397,284, attorney docket no. 25791.106, filed on 7/19/2002, (39) U.S. provisional patent application serial no. 60/398,061, attorney docket no. 25791.110, filed on 7/24/2002, (40) U.S. provisional patent application serial no, 60/405,610, attorney docket no. 25791.119, filed on 8/23/2002, (41) U.S. provisional patent application serial no. 60/405,394, attorney docket no. 25791.120, filed on 8/23/2002, (42) U.S. provisional patent application serial no. 60/412,177, attorney docket no. 25791.117, filed on 9/20/2002, (43) U.S. provisional patent application serial no. 60/412,653, attorney docket no. 25791.118, filed on 9/20/2002, (44) U.S. provisional patent application serial no. 60/412,544, attorney docket no. 25791.121, filed on 9/20/2002, (45) U.S. provisional patent application serial no. 60/412,187, attorney docket no. 25791.127, filed on 9/20/2002, and (46) U.S. provisional patent application serial no. 60/412,371, attorney docket no. 25791.129, filed on 9/20/2002, the disclosures of which are incorporated herein by reference.

Background of the Invention

[003] The present invention relates generally to tubular steel well casing and more particularly to enhancing residual stresses in the tubing after tubular expansion.

[004] Solid tubular casing of substantial length is used as a borehole liner in downhole drilling. The casing is comprised of end-to-end interconnected segments of steel tubing to protect against possible collapse of the borehole and to optimize well flow. The tubing often reaches substantial depths and endures substantial pressures. Sometimes, due to excessive pressure differentials, i.e. pressure within the tubing becomes much less than the external pressure acting on the tubing, one or more of the tubing segments may collapse. If so, a great amount of time and expense is needed to replace the collapsed tubing.

[005] Because the tubing is manufactured from steel, certain steps can be taken during manufacture to increase the strength of the tubing. One of the areas of great importance in achieving this is to be able to control the residual stress in the tubing. Each section of tubing has an outside diameter (OD) and an inside diameter (ID). A typical section of tubing produced today has tensile residual stresses at the OD and compressive residual stresses at the ID.

[006] It is present practice to expand the steel tubing downhole by using a mandrel. This is a cold-working process which presents substantial mechanical challenges. This technology is known as solid expandable tubular (SET) technology. This cold-working process deforms the steel without any additional heat beyond what is present in the downhole environment.

[007] An expansion cone, or mandrel, is used to permanently mechanically deform the pipe. The cone is moved through the tubing by a differential hydraulic pressure across the cone itself, and/or by a direct mechanical pull or push force. The differential pressure is pumped through an inner-string connected to the cone, and the mechanical force is applied by either raising or lowering the inner string.

[008] Progress of the cone through the tubing deforms the steel beyond its elastic limit into the plastic region, while keeping stresses below ultimate yield. Expansions greater than 20%, based on pipe ID, have been accomplished. However, most applications using 4 1/4 - 13 3/8 inch tubing have required expansions less than 20%.

[009] At the bottom of the SET system is a canister, known as the "launcher," that contains the expansion cone. The launcher is constructed of thin-wall, high-strength steel that has a thinner wall thickness than the expandable casing. Because the launcher has a thinner wall and its OD is the same as the drift of the previous casing string, it can be tripped into the hole through the previous casing string.

[0010] The difference in wall thickness of the launcher and the elastomer-coated hanger joint(s) allows the expanding pipe to be sealed, or "clad," to the previous casing string. The expanded pipe ends up with an OD that is greater than the OD of the launcher, due to its greater wall thickness. The ID of the pipe expands to the same ID of the launcher, which is a function of expansion cone OD.

[0011] When the tubing is expanded, changes take place with respect to the previously mentioned residual stresses at the OD and ID. Today's manufactured tubing typically has a negative tensile residual stress (i.e. compressive) at the OD. After expansion there are even greater negative tensile stresses at the OD. The result is that the tubular casing will have a greater potential for collapse after expansion.

[0012] One goal would be to produce manufactured tubing which initially has a positive tensile residual stress at the OD, so that after expansion, the tensile residual stress at the OD may be either zero or only slightly negative. This would result in improved collapse resistance.

[0013] It has been found that during bridge construction, an ultrasonic external impact treatment can be applied to bridge steel that converts tensile residual stress to compressive residual stress. However, there is no known way to convert such stresses in tubing, especially when the tubing is set in a borehole.

[0014] It would therefore be beneficial to be able to treat tubing, especially in a downhole environment, so that after expansion, the residual stress at the OD could be optimized for collapse resistance.

Summary Of The Invention

[0015] One embodiment accordingly, provides an apparatus and method for treating steel tubing. To this end, the apparatus includes an impact member, a plurality of movable impactors mounted to extend from the impact member, and an impact driver connected to move the impactors into repeated contact with an interior surface of the tubing circumferentially surrounding the impact member.

[0016] A principle advantage of this embodiment is that the impacting converts the residual stresses at the tubing ID to compressive stresses, which results in the residual stresses at the OD being tensile residual stresses.

Brief Description of the Drawings

[0017] Fig. 1 is a side view illustrating an embodiment of an expansion mandrel.

[0018] Figs. 2A-C are side views illustrating an embodiment of an expansion mandrel and a resulting expanded casing.

[0019] Fig. 3 is a cross-sectional view of the casing taken along the line 3-3 of Fig. 2C, before impacting.

[0020] Figs. 4 and 5 are schematic illustrations of embodiments of impactors.

[0021] Fig. 6 is a cross-sectional view of the casing of Fig. 3, after impacting.

[0022] Fig. 7 is a perspective view schematically illustrating another embodiment of an impact member.

[0023] Fig. 8 is a perspective view schematically illustrating an embodiment of a mandrel used during a manufacturing process for a length of casing.

Detailed Description of the Illustrative Embodiments

[0024] An expansion mandrel is generally designated 10 in Fig. 1, and includes a main body 12 having a longitudinal axis L which extends between a first end 14 and a second end 16 of the main body 12. An external surface 18 of body 12 has a first diameter D1 at first end 14, and a second diameter D2, larger than D1, at second end 16, interconnected by a tapered expansion portion E. The first end 14 of body 12 is a leading end being of the smaller diameter D1, and the second end 16 is a trailing end being of the larger diameter D2.

[0025] Mandrel 10, Figs. 2A, 2B and 2C, is used for expanding an elongated section of steel casing 30 defining an elongated passage 32 therein. Mandrel 10 is positioned, for example in a position A, Fig. 2A, and is axially moved through the passage 32 to an exemplary position B, Fig. 2B, and position C, Fig. 2C, to expand passage 32 from an original diameter 0 to an expanded final diameter F.

[0026] After expansion, as described above, the residual stresses in the casing 30 are changed, Fig. 3, which illustrates a section of the expanded casing 30 having increased negative tensile (i.e. compressive) residual stresses at the OD and positive tensile residual stresses at the ID divided by a concentric mid plane 38.

[0027] In order to enhance collapse resistance of the expanded casing, an impact member 40, Fig. 4, includes a plurality of movable impactors 42 mounted to extend from a rotating impact member 40, as indicated by the directional arrow designated R, an impact driver 44 is connected to ultrasonically move the impactors 42 into repeated contact with the ID of casing 30 as impact member 40 rotates. In this embodiment, the impactors 42 can be reciprocally movable as indicated in phantom.

[0028] The impact member 40 may be moved through the passage 32 following expansion by the mandrel 10. This can be accomplished by combining the impact member 40 with mandrel 10, Fig. 4, or by attaching an impact member 40, Fig. 5, to follow mandrel 10 through passage 32. The ultrasonic impacting can also be applied to treat casing as part of the manufacturing process prior to downhole positioning.

[0029] As a result of the foregoing ultrasonic impacting, the residual stress at the OD of casing 30, Fig. 6, can be optimized for collapse resistance so that there is an increased negative tensile residual stress at the ID resulting in an increased positive tensile residual stress at the OD. In addition to ultrasonic impacting, a shot peening process, a vibration process, or a pneumatic blast process, for example, generated from an impact member 40x, Fig. 7, moved within the passage 32 along a path P, can be used to provide the increased negative tensile residual stress at the ID.

[0030] The foregoing suggests increasing collapse resistance through different residual stress distribution.

[0031] It is possible to create opposite residual stress distribution during pipe manufacturing (tensile residual stresses on the OD and compressive residual stress on the ID surfaces). This is an improvement over the conventional value of the stresses that we have today. This can be achieved in pipe manufacturing by a combination of the rolling, heating and cooling procedures and process parameters. For instance elimination of the final sizing will lead to significantly decreasing the level of the compressive residual stress, or even to tensile residual stress on pipe OD. Also, a mandrel 100, Fig. 8, can be positioned and moved relative to passage 32 of casing 30 during the manufacturing process, sufficient to provide the increased negative tensile stress at the ID.

[0032] Another approach is stress relieving the welded pipe after manufacturing by longer or better tempering or ultrasonic impact treatment.

[0033] And finally, applying the ultrasonic impact treatment in-situ (i.e., down hole) during or immediately after expansion.

[0034] Although illustrative embodiments have been shown and described, a wide range of modification, change and substitution is contemplated in the foregoing disclosure and in some instances, some features of the embodiments may be employed without a corresponding use of other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the embodiments disclosed herein.

Claims

What is claimed is:

1. An apparatus for treating steel tubing comprising:
   an impact member;
   a plurality of movable impactors mounted to extend from the impact member; and
   an impact driver connected to move the impactors into repeated contact with an interior surface of the tubing which circumferentially surrounds the impact member.
2. The apparatus as defined in claim 1 wherein the impactors are reciprocally movable.
3. The apparatus as defined in claim 1 wherein the impact member is rotatably movable.
4. The apparatus as defined in claim 1 wherein the movement of the impactors is ultrasonic.
5. A method for treating steel tubing comprising:
   providing an elongated section of steel tubing having an outer circumferential surface and an inner circumferential surface defining an elongated axial passage through the tubing;
   providing an impact member for travel through the length of the axial passage;
   mounting a plurality of movable impactors to extend from the impact member;
   driving the impactors for repeated contact with the inner circumferential surface; and
   moving the impact member through the tubing so that the impactors contact the inner circumferential surface along the length of the axial passage.
6. The method as defined in claim 5 further comprising:
   reciprocally driving the impactors.
7. The method as defined in claim 5 further comprising:
   rotatably driving the impact member.
8. The method as defined in claim 5 further comprising:
   ultrasonically moving the impactors.
9. An apparatus for treating steel tubing comprising:
   an impact member;
   a plurality of movable impactors mounted to extend from the impact member;
   an impact driver connected to move the impactors into repeated contact with an interior surface of the tubing circumferentially surrounding the impact member;
   an expansion mandrel movable along the interior surface for radially expanding the tubing; and
   the impact member positioned to follow the mandrel through the tubing.
10. The apparatus as defined in claim 9 wherein the impact member is in a housing separate from the expansion mandrel.
11. The apparatus as defined in claim 10 wherein the impactors reciprocate radially from the housing.

12. An apparatus for treating steel tubing comprising:

an impact member;

a plurality of movable impactors mounted to extend from the impact member;

an impact driver connected to move the impactors into repeated contact with an interior surface of the tubing circumferentially surrounding the impact member; and

an expansion mandrel combined with the impact member and movable along the interior surface for radially expanding the tubing.

13. The apparatus as defined in claim 12 wherein the mandrel and the impact member are in a common housing.

14. The apparatus as defined in claim 13 wherein the impactors reciprocate from the housing.

15. A method for treating steel tubing comprising:

providing an elongated section of steel tubing having an outer circumferential surface and an inner circumferential surface defining an elongated axial passage through the tubing;

providing an impact member for travel through the length of the axial passage;

mounting a plurality of movable impactors to extend from the impact member;

driving the impactors for repeated contact with the inner circumferential surface;

moving an expansion mandrel through the tubing for radially expanding the tubing; and

moving the impact member through the tubing subsequent to the expansion mandrel so that the impactors contact the expanded inner circumferential surface along the length of the axial passage.

16. The method as defined in claim 15 further comprising:

providing a housing for the impact member.

17. The method as defined in claim 16 further comprising:

reciprocating the impactors radially from the housing.

18. The method as defined in claim 16 further comprising:

rotating the impact member.

19. The method as defined in claim 16 further comprising:

reciprocating the impact members and rotating the housing.

20. A method for treating steel tubing comprising:

providing an elongated section of steel tubing having an outer circumferential surface and an inner circumferential surface defining an elongated axial passage through the tubing;

providing an impact member for travel through the length of the axial passage;

mounting a plurality of movable impactors to extend from the impact member;

driving the impactors for repeated contact with the inner circumferential surface; and

moving an expansion mandrel through the tubing for radially expanding the tubing, the mandrel combined with the impact member so that the impactors contact the inner circumferential surface along the length of the axial passage after expansion.

21. An apparatus for treating steel tubing comprising:

an elongated section of steel tubing having an OD and an ID defining an elongated axial passage through the tubing; and

an impact member movably positioned in the passage, the impact member including means for impacting the ID of the tubing sufficient to increase negative tensile residual stress at the ID.

22. A method for treating steel tubing comprising:

providing an elongated section of steel tubing having an OD and an ID defining an elongated axial passage through the tubing; and

moving an impact member through the passage for impacting the ID of the tubing sufficient to increase negative tensile residual stress at the ID.

23. A method for treating steel tubing comprising:

manufacturing an elongated section of steel tubing having an OD and an ID defining an elongated axial passage through the tubing; and

positioning and moving a mandrel through the passage sufficient to increase negative tensile residual stress at the ID.

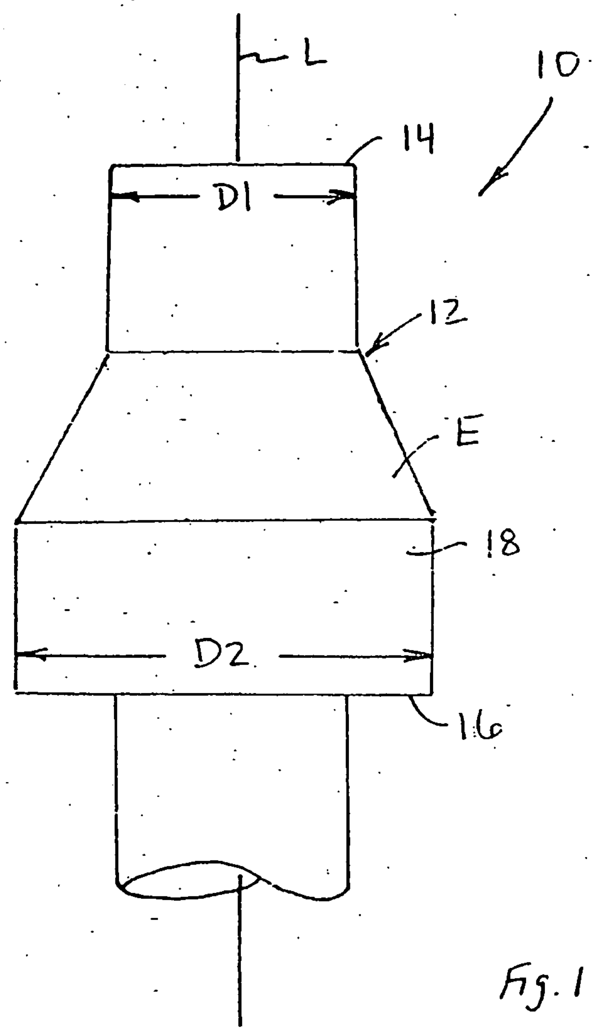

Fig. 1

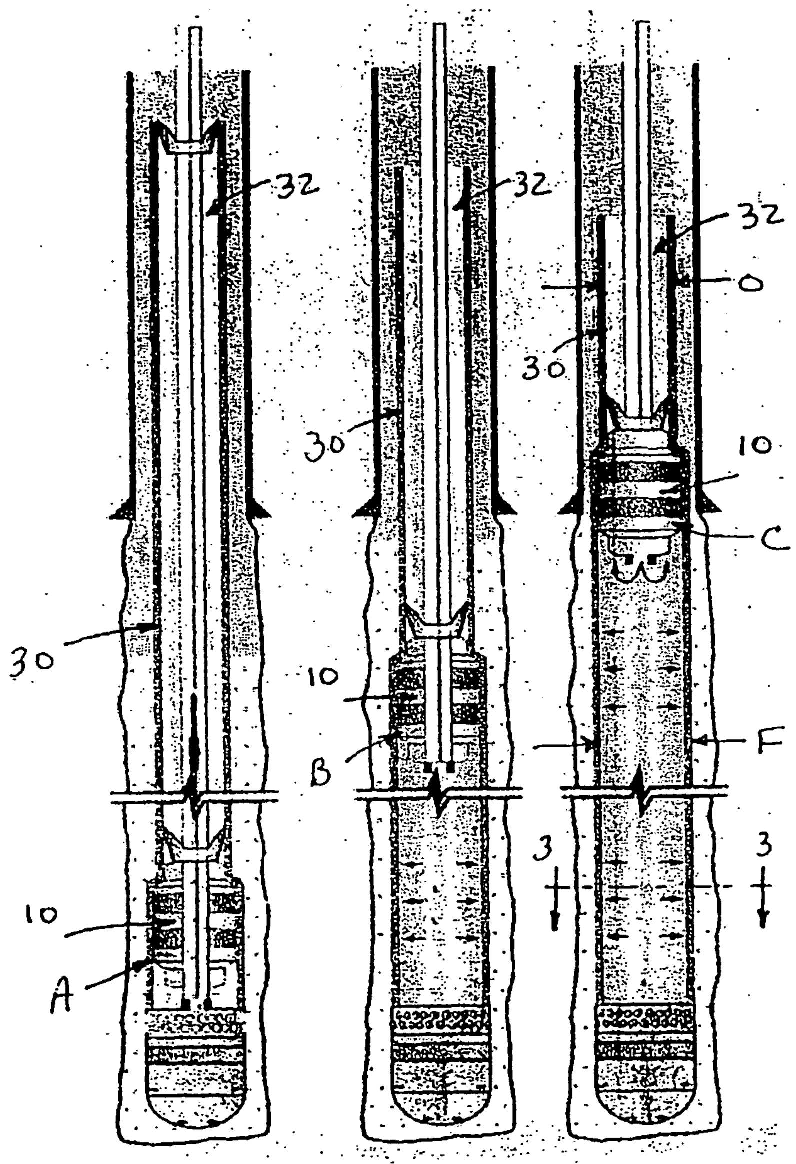

Fig. 2A Fig. 2B Fig. 2C

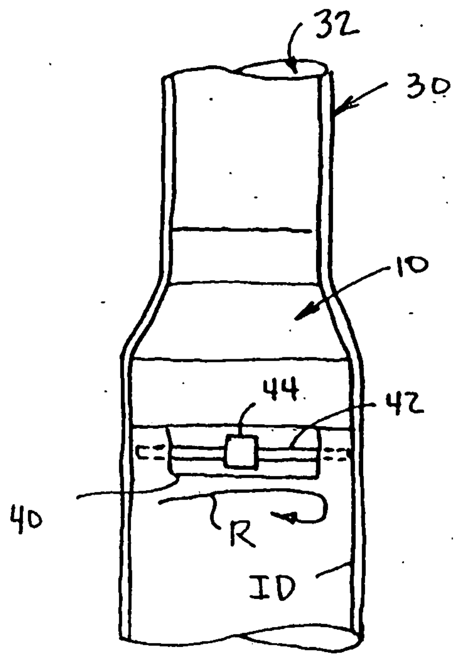

Fig.4

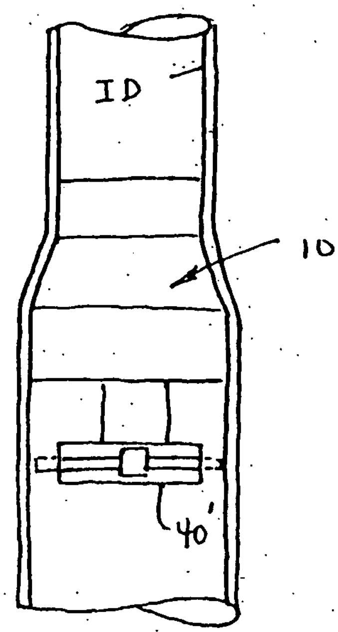

Fig. 5

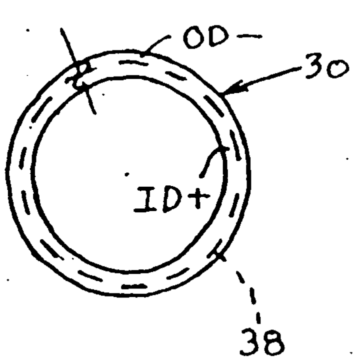

Fig.3

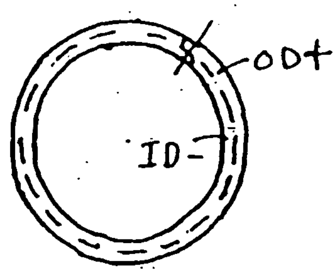

Fig. 6

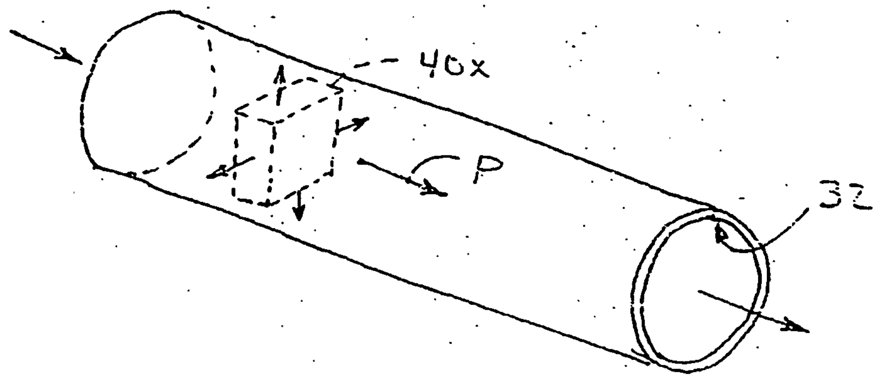

Fig.7

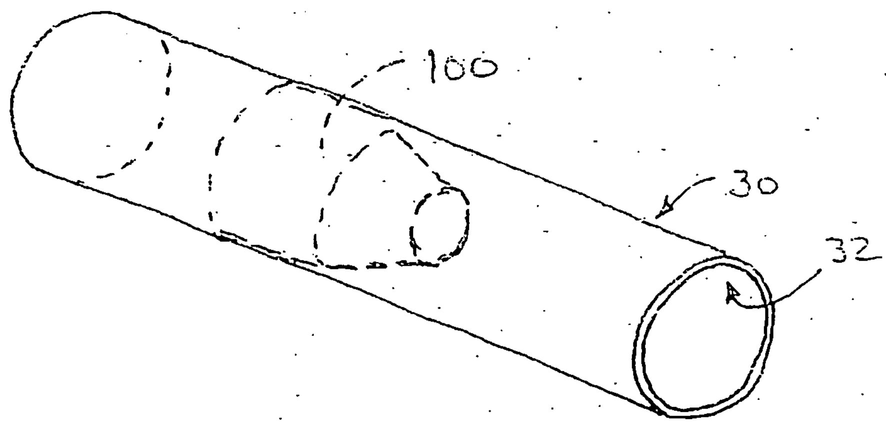

Fig.8